

# An Update on the Airborne Lunar Spectral Irradiance (Air-LUSI)



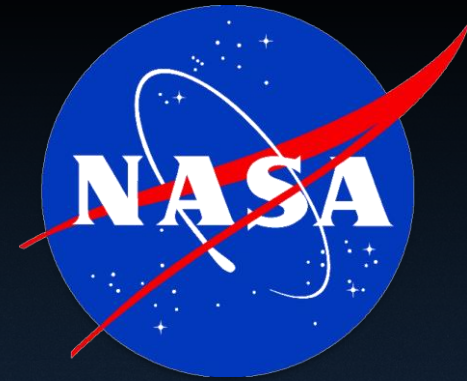
K. Turpie, UMBC / JCET

MODIS/VIIRS Calibration Workshop  
26 February 2021





# Air-LUSI AITT Program Team



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# ADVANCEMENT OF ABSOLUTE LUNAR CALIBRATION

Lunar calibration potentially can provide cost-effective absolute calibration of reflected solar bands that is accurate and inter-consistent across multiple sensors.

## Benefits

- A permanent (and retrospective) common reference not affected by climate.
- Inter-consistent Earth climate data records across series of missions and data gaps.
- Intercalibration of sensors between international partners.
- Enable future constellation architectures and very small or inexpensive platforms.
- Enhanced calibration for aquatic remote sensing.

## Cost: Low

## Steps

- **Improve lunar calibration reference:**
  - Acquire high-accuracy, SI-traceable measurements of the Moon.
  - Use new measurements to advance the lunar model.
- **Improve techniques for lunar measurements by satellite sensors.**

## Primary:

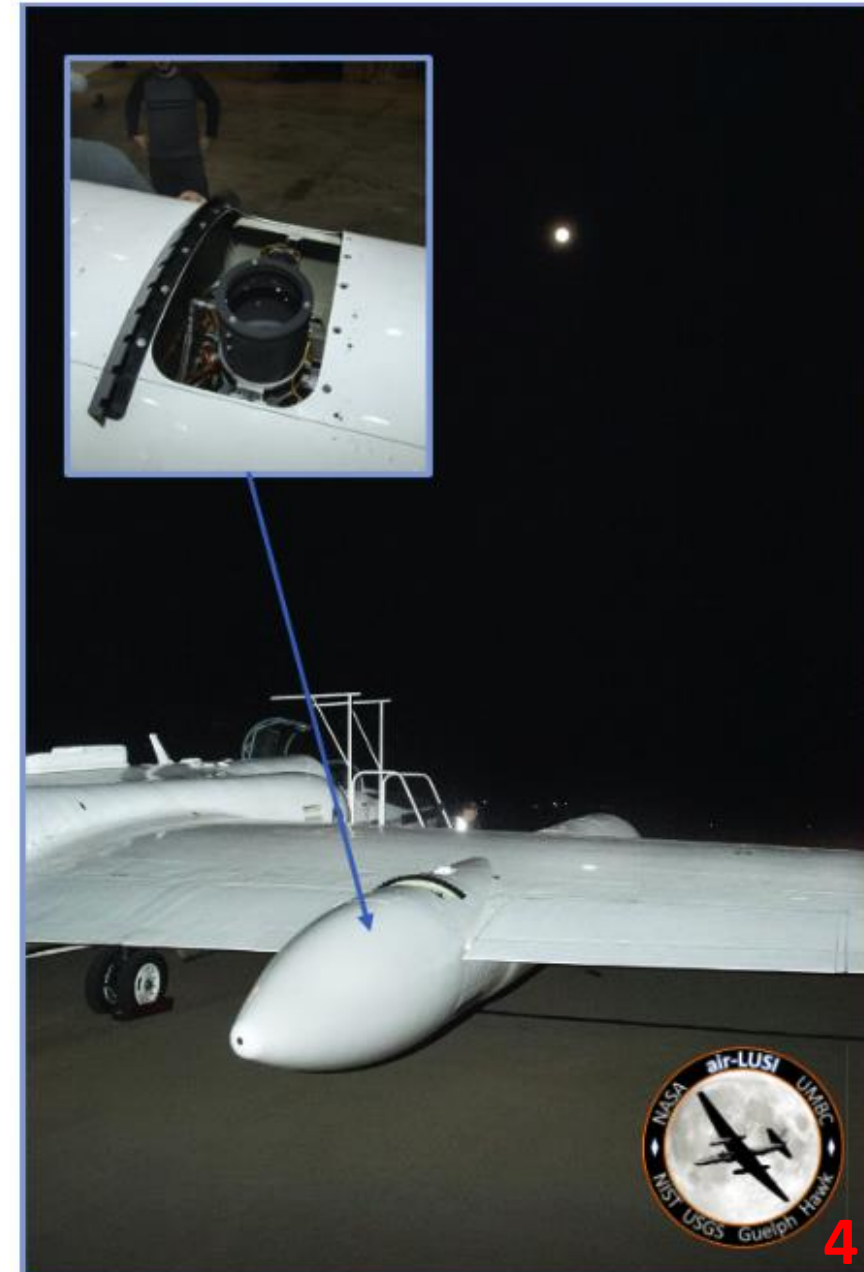
*To make very accurate, SI-traceable lunar spectral irradiance measurements with high spectral resolution from well above 90% the atmosphere. Target uncertainty is  $<0.5\%$  ( $k=1$ ).*

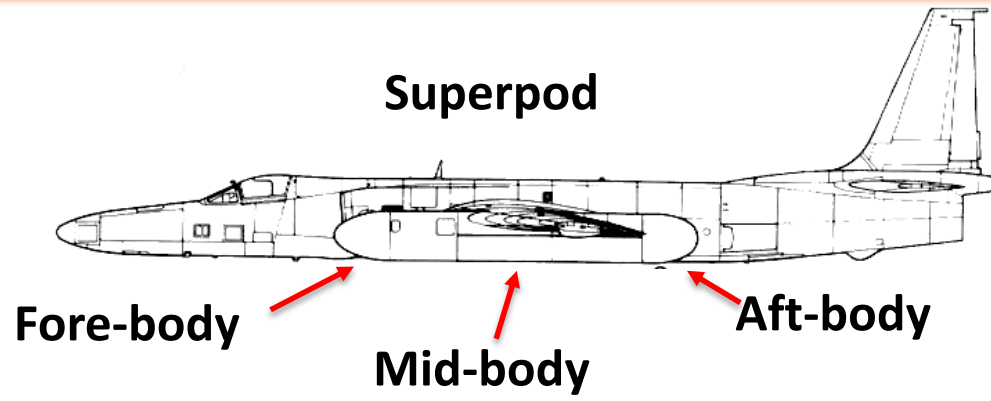
## Secondary:

*The improvement of satellite lunar calibration vis-à-vis a high accuracy, absolute lunar model and provide a validation resource for similar efforts. Air-LUSI also intends to improve its measurement accuracy with each campaign. Calibration improvements between Air-LUSI and MLO-LUSI are shared.*

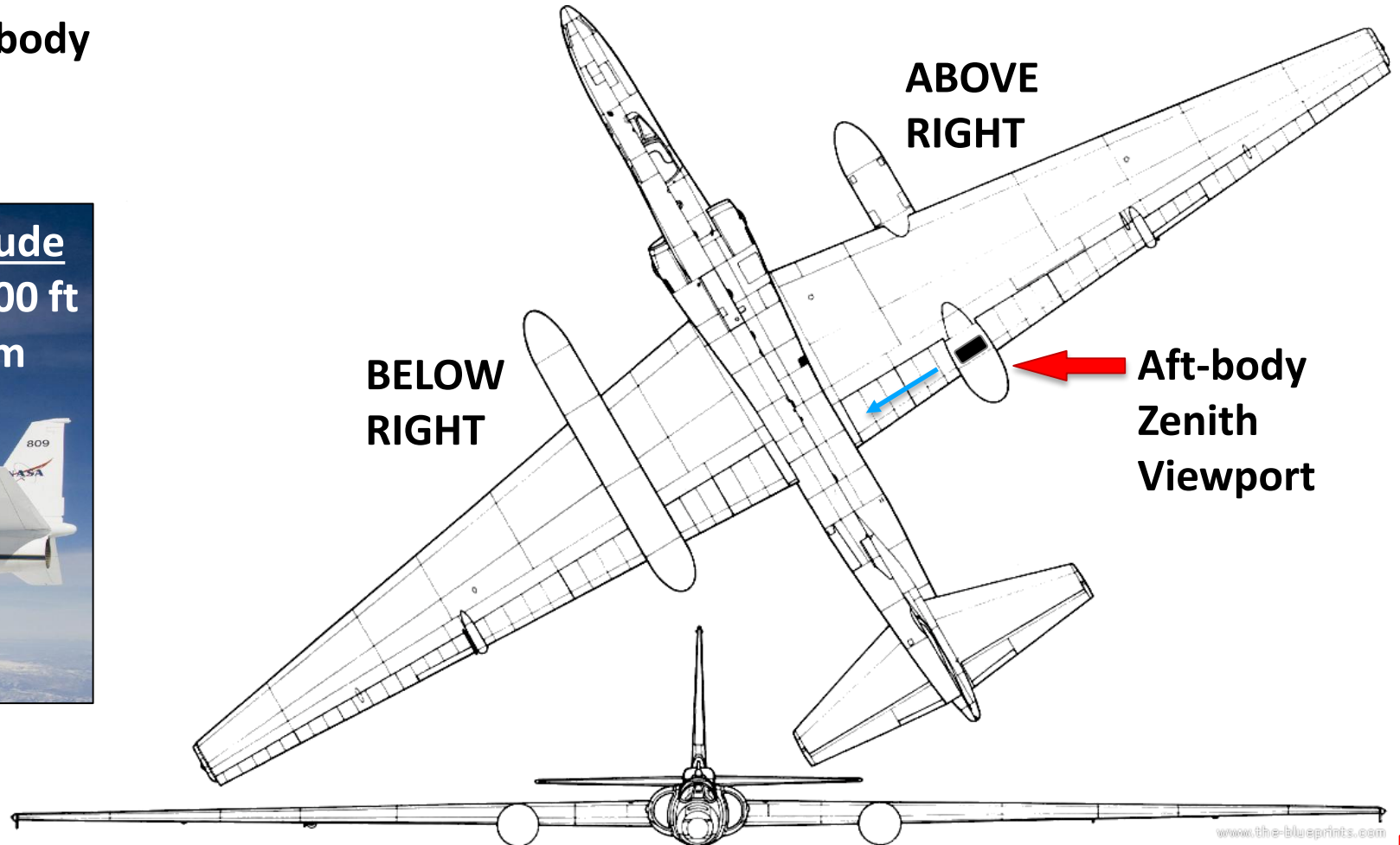
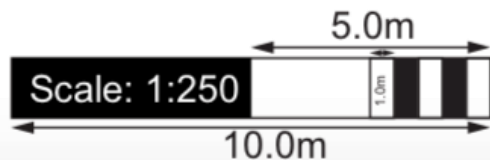
## Characteristics:

- High accuracy:  $< 1.0\%$  ( $k=1$ ), 415 -1000 nm (target  $<0.5\%$ )
- High spectral resolution: 3.7 nm with 0.8 nm sampling (300 – 1100 nm)
- Small atmospheric correction:  $\sim 3\%$  from molecular scatter and  $O_3$  over small region
- Calibration checked before and after use
- Calibration monitored up to the point of data collection





- The telescope and robotic mount are in Superpod Aft-body.
- The sensor enclosure and control computer are in Mid-body.
- IRIS telescope views to port through Aft-body Zenith Viewport.

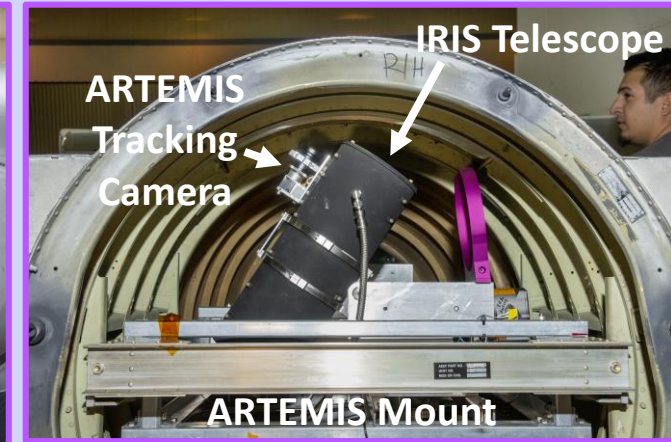


# Instrument Subsystems

## ARTEMIS – Autonomous, Robotic Telescope Mount Instrument Subsystem



- Uses tracking camera on telescope and computer controlled PID loop.
- Keeps telescope fixed on the Moon to within  $0.1^\circ$ .

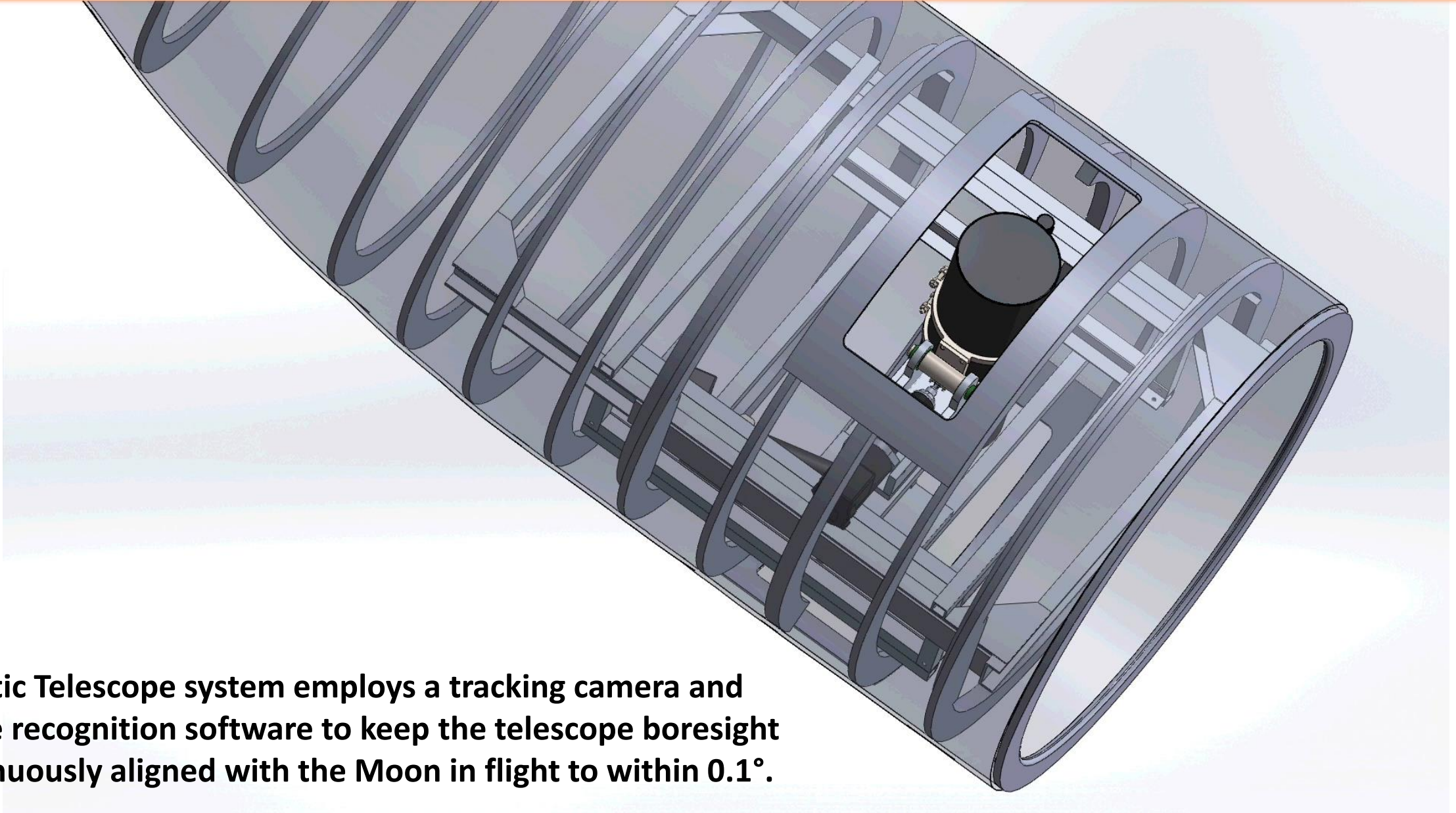


## IRIS – Irradiance Instrument Subsystem



- A non-imaging telescope (integrating sphere at focal point).
- Light fed via a fiber optic cable to a spectrograph.
- On-board LED validation source.
- Instrument enclosure keeps the spectrograph and validation source at surface-level P & T during flight.





Robotic Telescope system employs a tracking camera and image recognition software to keep the telescope boresight continuously aligned with the Moon in flight to within  $0.1^\circ$ .







Mobile Pilot  
Communication

Air-LUSI network  
and telemetry

Robotics

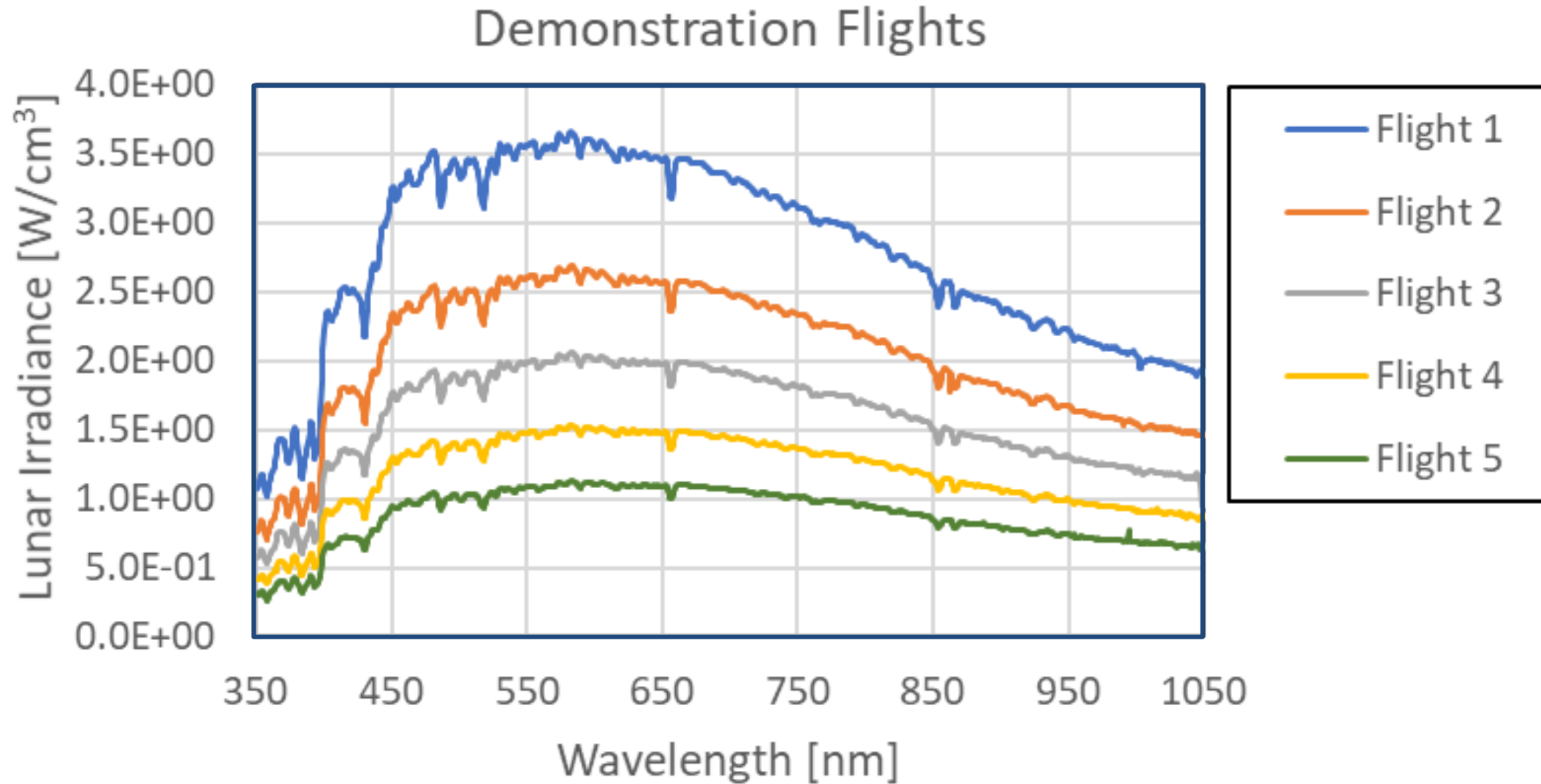
Instrument  
Function

Air-LUSI “Mission Control”

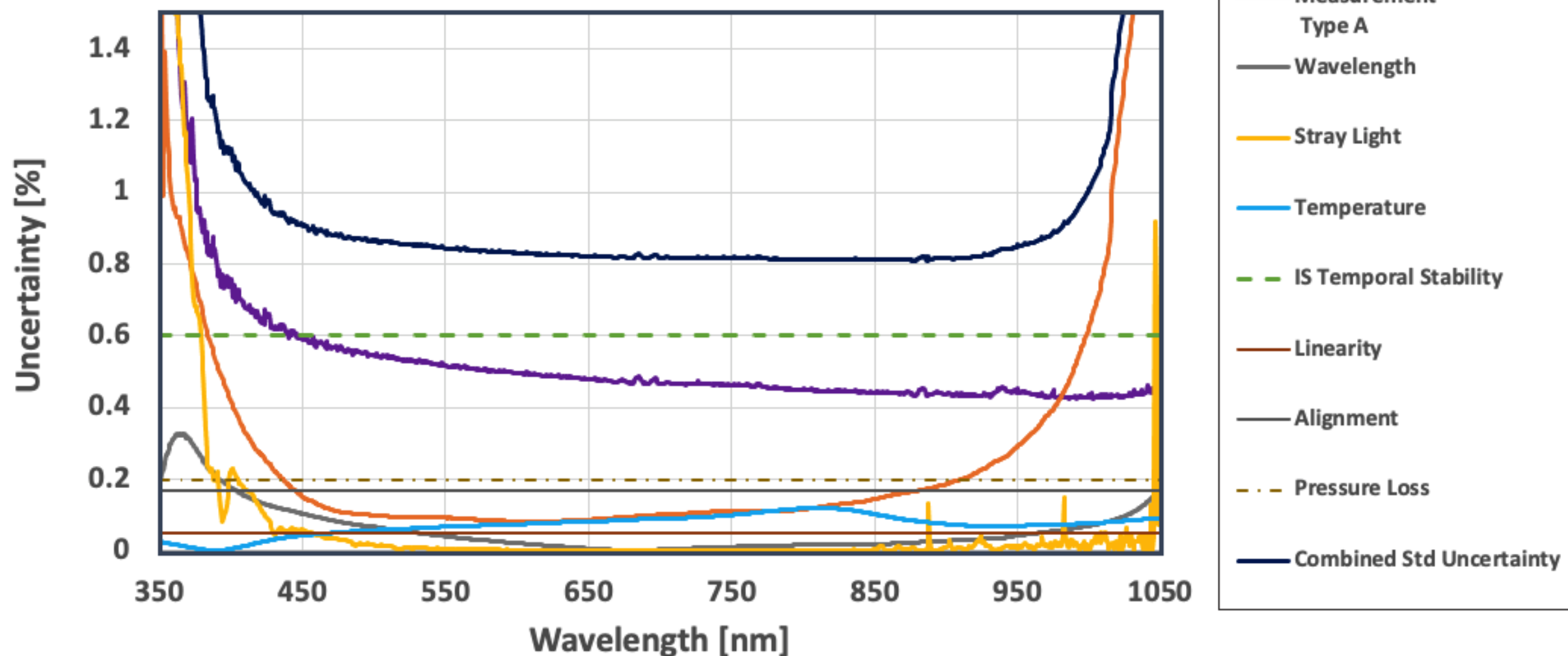








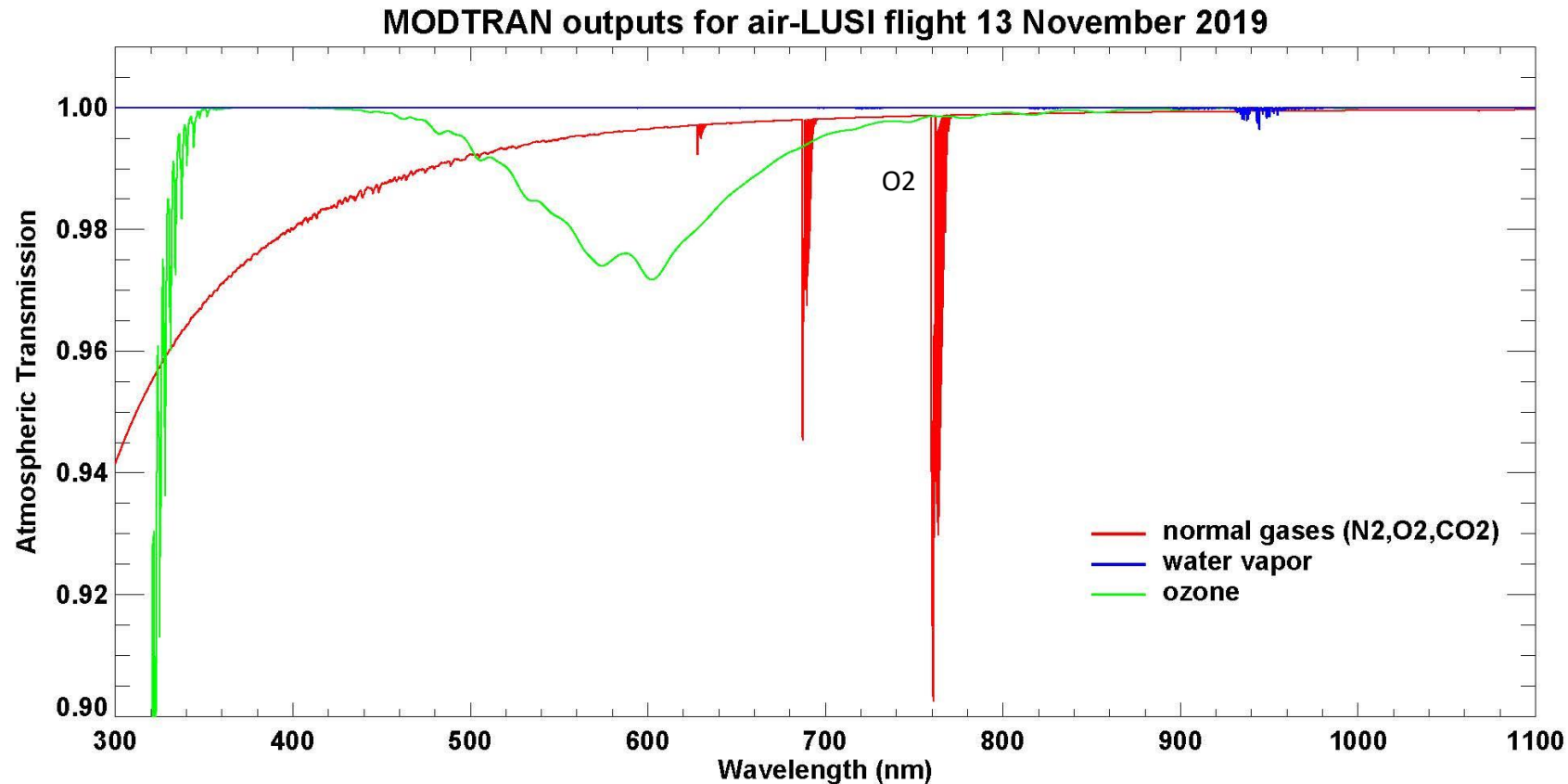
## Air-LUSI Lunar Irradiance Uncertainty Budget



## MODTRAN atmospheric transmission for Air-LUSI flight 1

MODTRAN setup:

- slant path to space from 21.215 km altitude, zenith angle = 22.047°
- 1976 US Standard Atmosphere, 380 ppmv CO<sub>2</sub>



## Error propagation for atmospheric correction:

The exo-atmospheric lunar spectral irradiance  $E_{LUSI}$  is computed by dividing the at-sensor lunar spectral irradiance by the transmission  $T_s$  as a function of  $\lambda$ . The relative uncertainty is RSS with the at-sensor uncertainty of the transmittance.

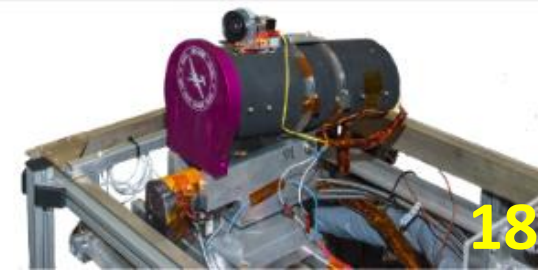
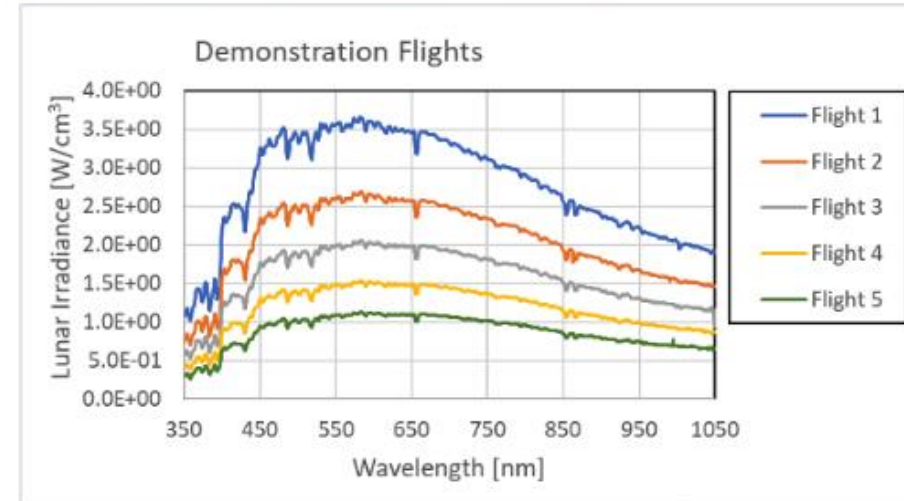
$$E_{LUSI}(\lambda) = \frac{E_{IRIS}^{Moon}(\lambda)}{T_s(\lambda)} \qquad \left( \frac{\sigma_{E_{LUSI}}}{E_{LUSI}} \right)^2 = \left( \frac{\sigma_{E_{IRIS}^{Moon}}}{E_{IRIS}^{Moon}} \right)^2 + \left( \frac{\sigma_{T_s}}{T_s} \right)^2$$

Assuming a conservative 10% error in the model, maxima are given at the following wavelengths, which has a nearly insignificant impact on the at-sensor uncertainty.

$$\left( \frac{\sigma_{T_s}}{T_s} \right)^2 \approx 0.20\% \quad @\lambda = 400 \text{ nm}$$

$$\left( \frac{\sigma_{T_s}}{T_s} \right)^2 \approx 0.32\% \quad @\lambda = 620 \text{ nm}$$

- Demonstration Flight Campaign November 2019 was successful.
  - Lunar Spectral Irradiance for 5 nights at phases: 10°, 21°, 34°, 46° and 59°
  - Error budget gives an uncertainty of  $< 1.0\%$  ( $k=1$ ), which can be improved  
*Air-LUSI is ready for operational use*
- Post-Campaign Activities
  - Wrapping up data reprocessing and ROLO comparison
  - Doing initial work on repairs and maintenance
  - Some tasks dependent on lab access were delayed efforts b/c of COVID
- Current Applications
  - Comparing air-LUSI to ESA LIME model and data from Tenerife
  - Can compare to CNES PLEIADES and NASA Terra MODIS
  - GSICS community expressed strong interest in more comparisons
- Future data collection depends on funding and aircraft availability
- Because of aircraft availability, we may be delayed until FY22





air-LUSI Team (Left to Right) – Steven Grantham, Andrew Newton, Kevin Turpie, John Woodward, Tom Larason, Stephen Maxwell (not shown: Steve Brown, Andrew Gadsden, Andrew Cataford, and Tom Stone)

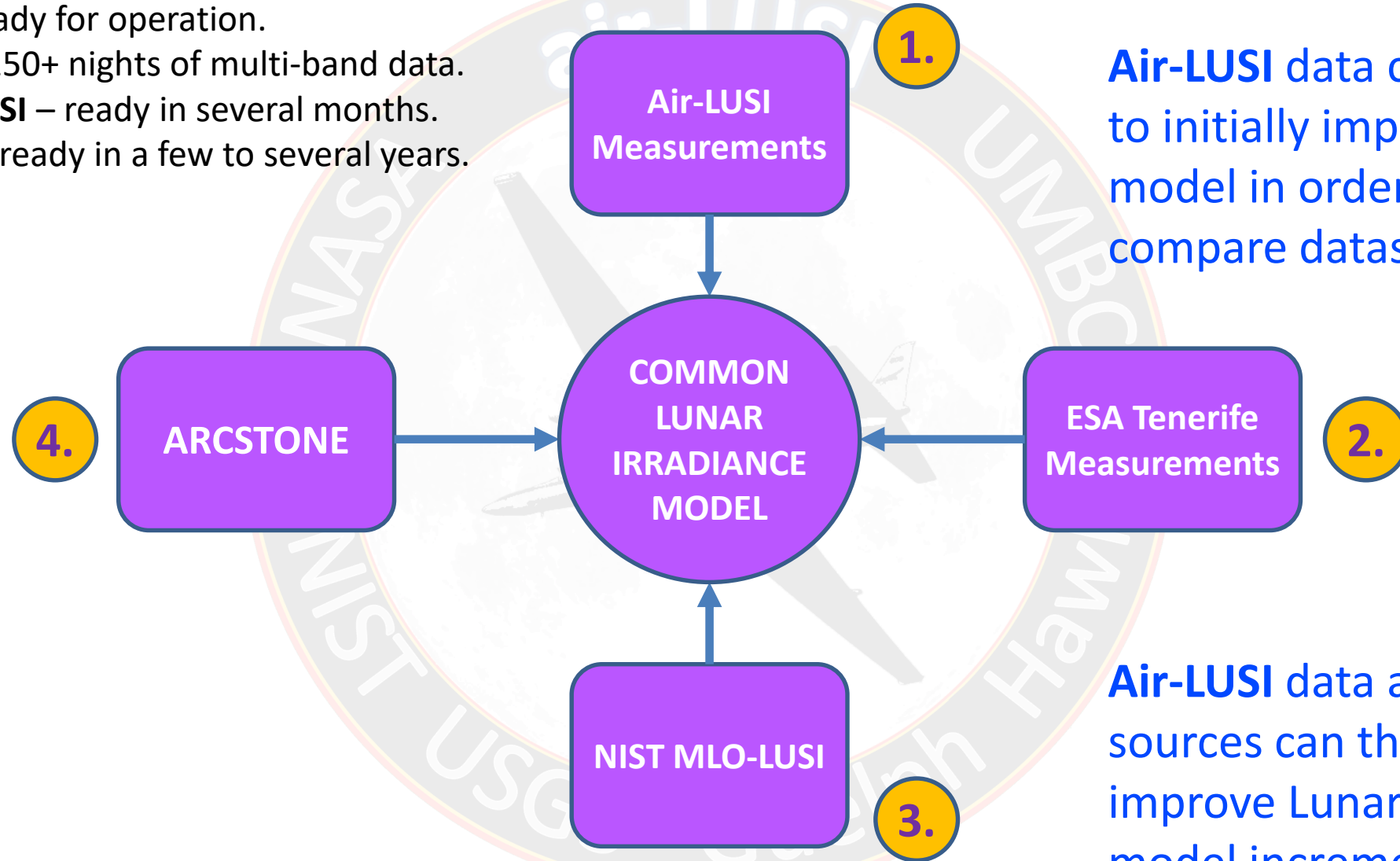


**BACKUP SLIDES**

Parameter	Air-LUSI (airborne)	MLO-LUSI (ground)	ARCSTONE (space)
Altitude	Above 95% of atmosphere	Above 30% of atmosphere	Measurements from LEO
Measurement	Lunar spectral irradiance	Lunar spectral irradiance	Lunar spectral irradiance
Atmospheric Corrections	Modeling @ max 3% uncertainty	Langley approach	None
Sampling Frequency	5 - 7 observations per campaign	Nightly observations (weather *)	Every 12 hours
Duration	20 flights over 2+ years	3+ years	3+ years
Spectral Range	VNIR (SWIR possible)	VNIR (SWIR planned)	VNIR-SWIR
Accuracy Goals	< 0.5% (k=1)	< 0.5% (k=1)	< 0.5% (k=1)
Calibration Approach	NIST source	NIST source	On-orbit to SSI (TSIS/SIM, 0.2%)
Role	New Lunar Reference/Validation	New Lunar Reference (50% app**)	New Lunar Reference (75% app**)
Readiness	TRL 8 – 9	TRL 8	TRL 5 by June 2021
Funding	NASA / NIST	NIST	NASA ESTO IIP / SBIR

# Air-LUSI and Community Reference Development

1. Air-LUSI is ready for operation.
2. ESA/LIME – 150+ nights of multi-band data.
3. NIST MLO-LUSI – ready in several months.
4. ARCSTONE – ready in a few to several years.

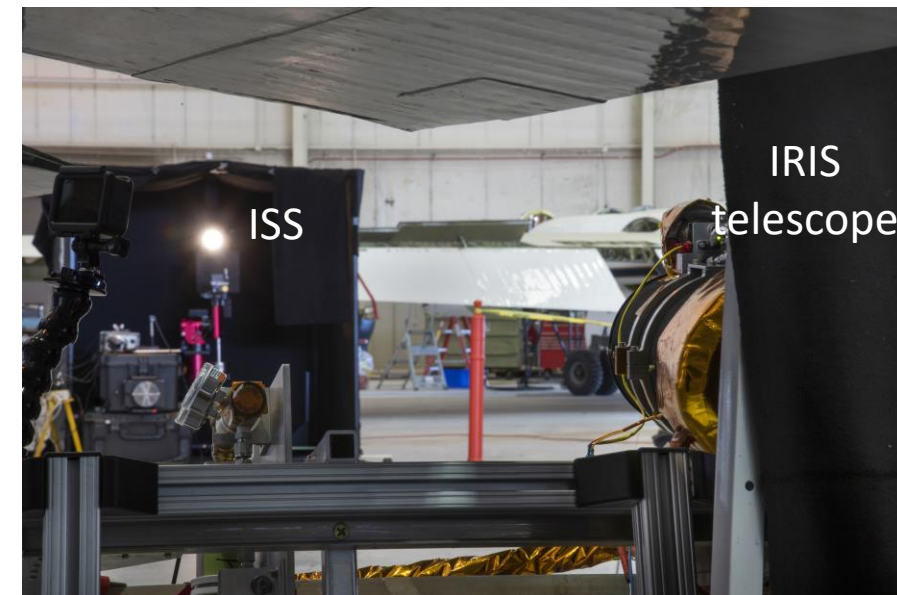
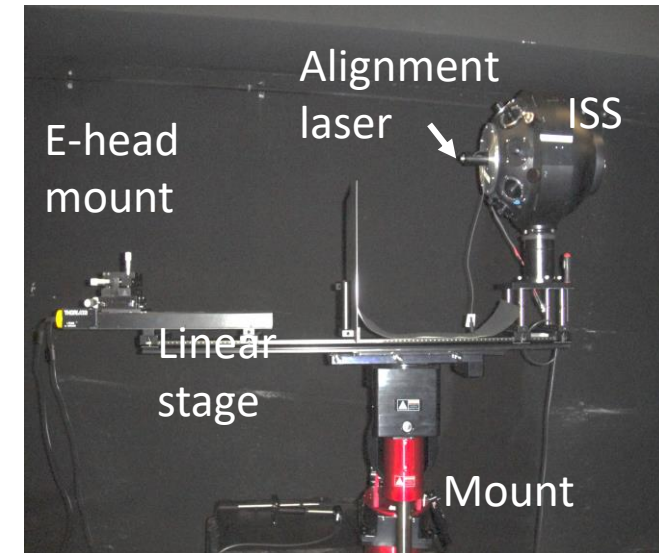
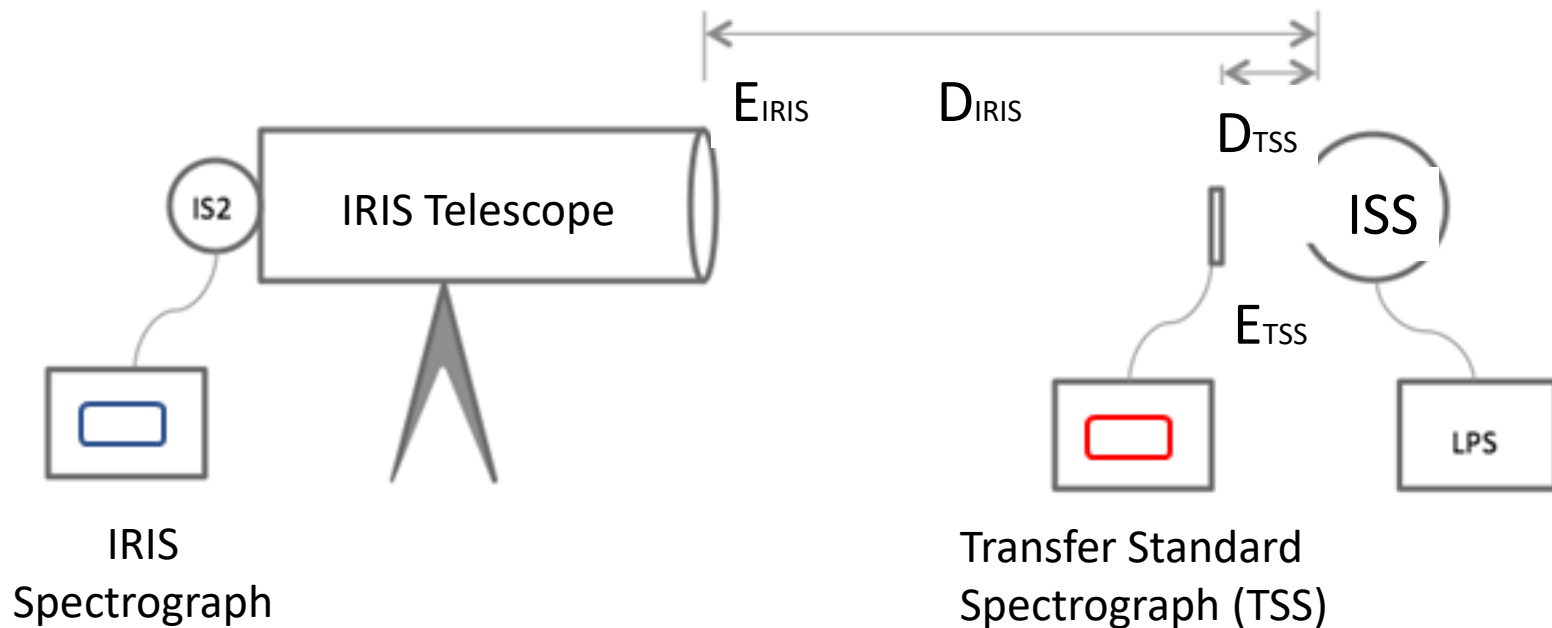


**Air-LUSI** data can be used to initially improve the model in order to inter compare datasets.

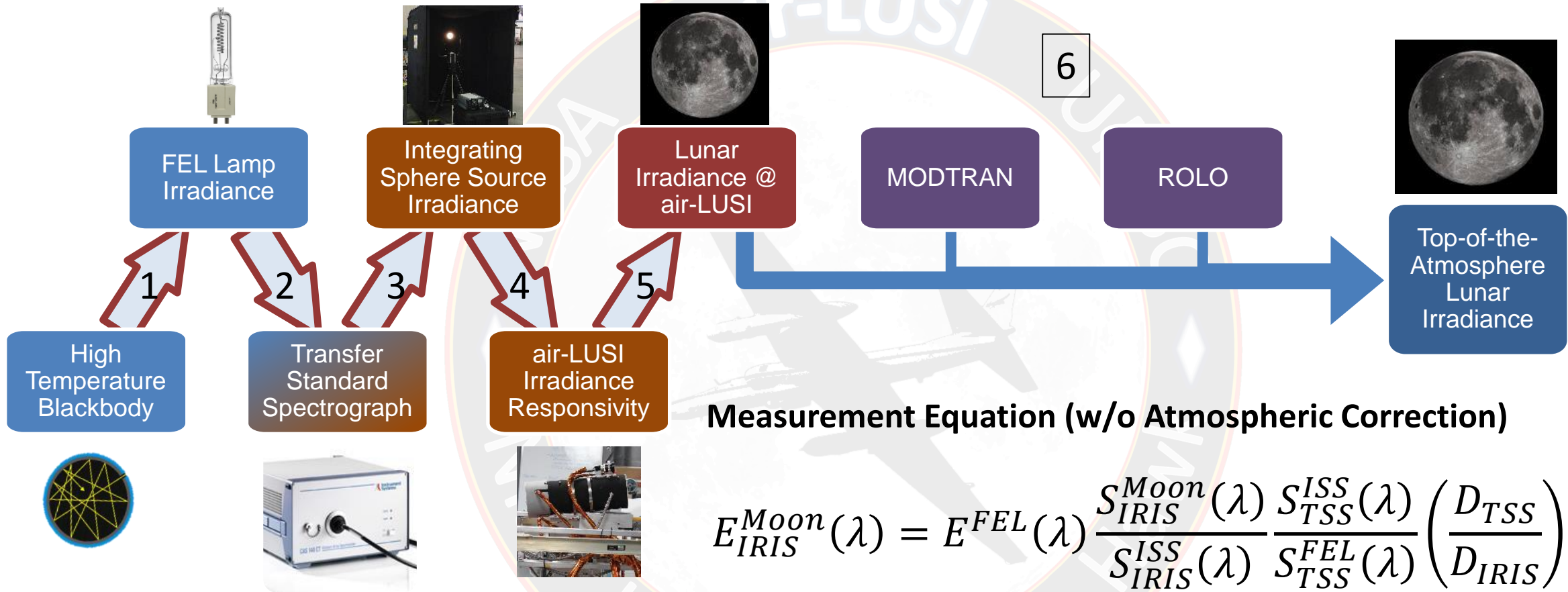
**Air-LUSI** data and other data sources can then be used to improve Lunar Reference model incrementally.

Air-LUSI is calibrated by observing a lamp-illuminated integrating sphere source (ISS) with the approximate angular subtense of the full moon. The output of the ISS is measured by a transfer standard spectrograph (TSS) that holds an SI-traceable scale form NIST.

The inverse square law and measurements of the distance between the integrating sphere and the transfer standard and IRIS are used to transfer the scale to IRIS.



## Air-LUSI Calibration/Lunar Measurement Chain



**Measurement Equation (w/o Atmospheric Correction)**

$$E_{IRIS}^{Moon}(\lambda) = E^{FEL}(\lambda) \frac{S_{IRIS}^{Moon}(\lambda)}{S_{IRIS}^{ISS}(\lambda)} \frac{S_{TSS}^{ISS}(\lambda)}{S_{TSS}^{FEL}(\lambda)} \left( \frac{D_{TSS}}{D_{IRIS}} \right)^2$$

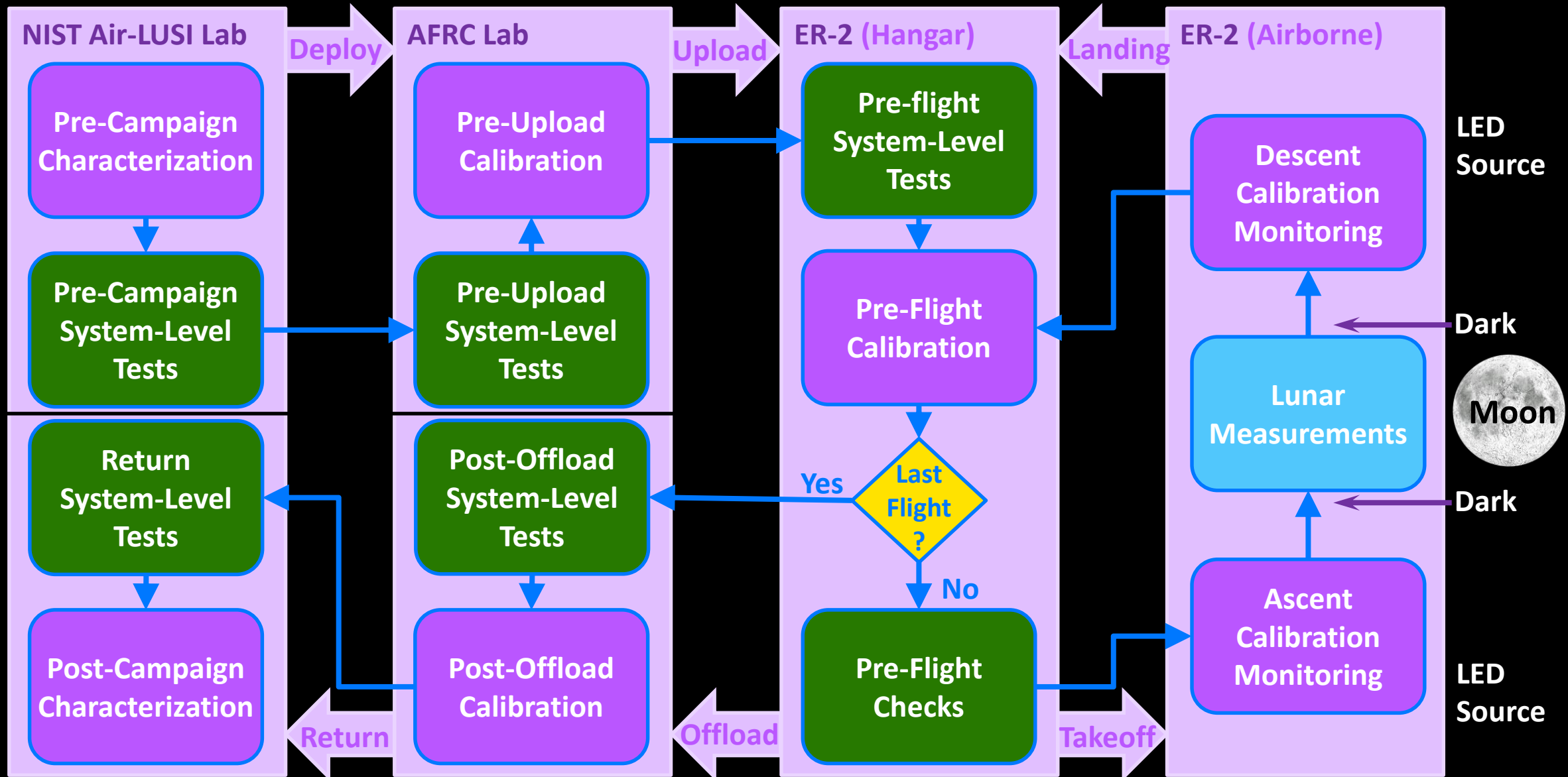
E – Irradiance, S – Signal, D – Distance,  $\lambda$  – wavelength.

Subscripts are the measuring instrument: Transfer Standard Spectrograph (TSS) or IRIS.

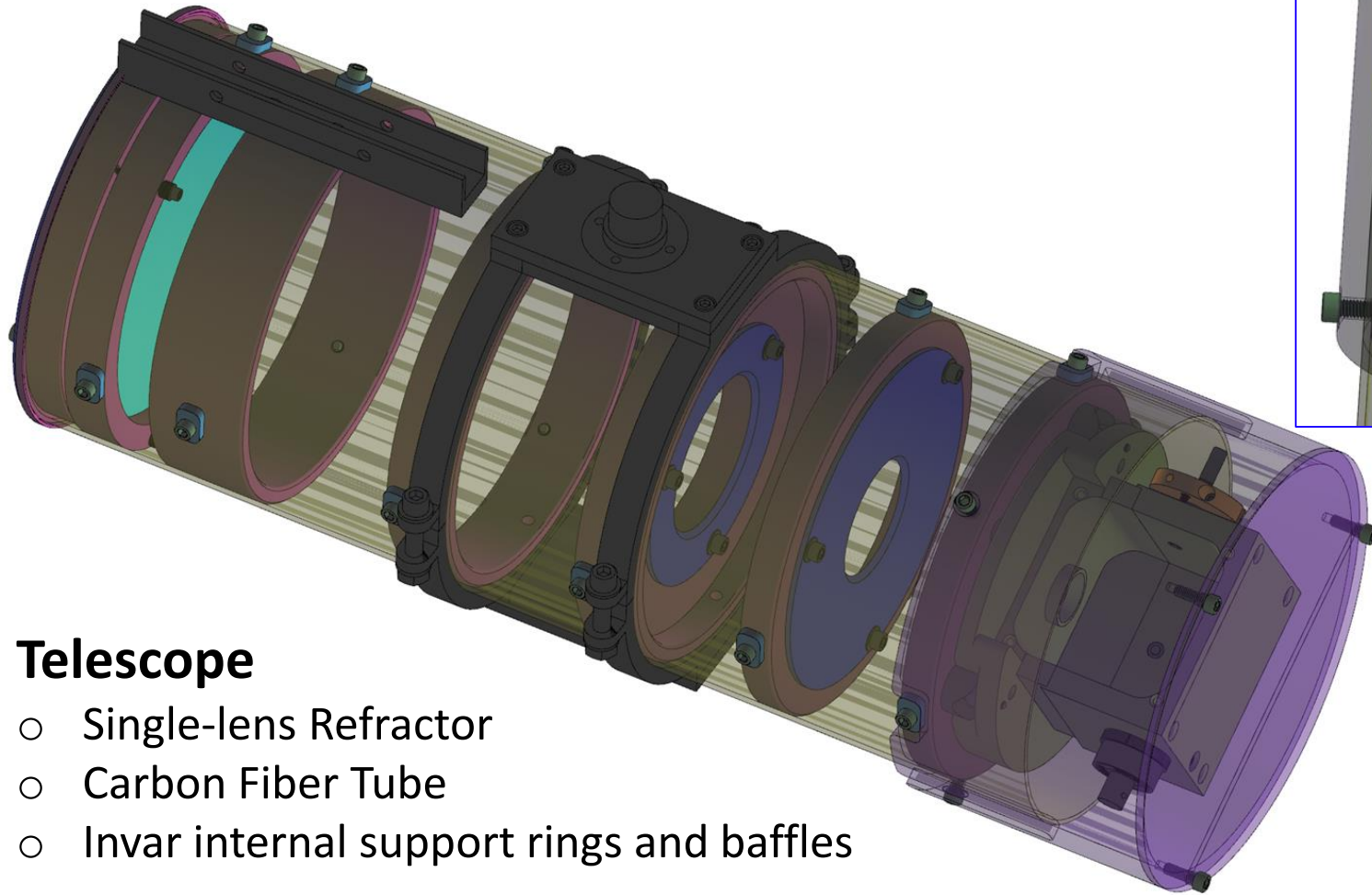
Superscripts are light source: FEL, Integrating Sphere Source (ISS), or Moon.

# Measurement Flow Chart

Air-LUSI

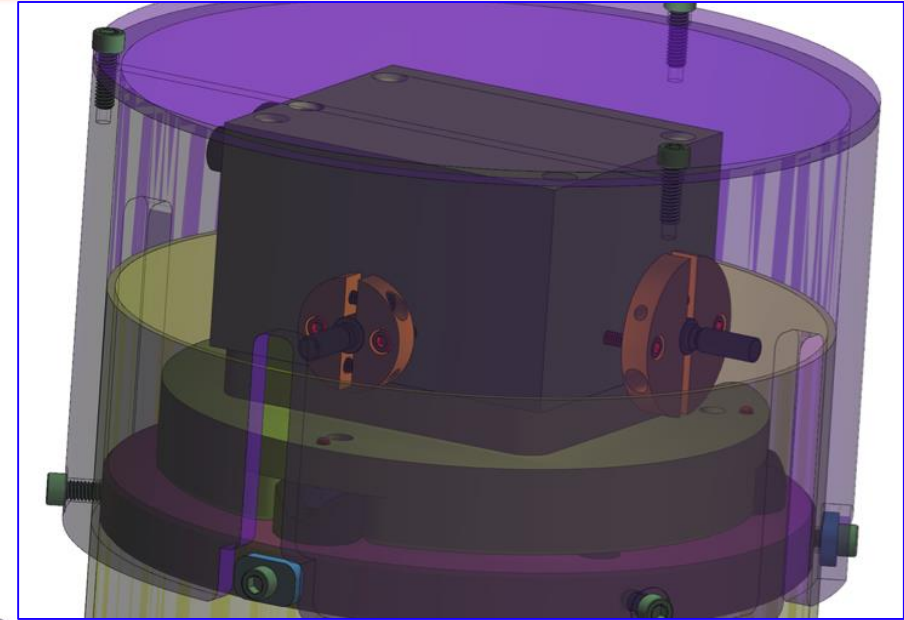


# Telescope Design



## Telescope

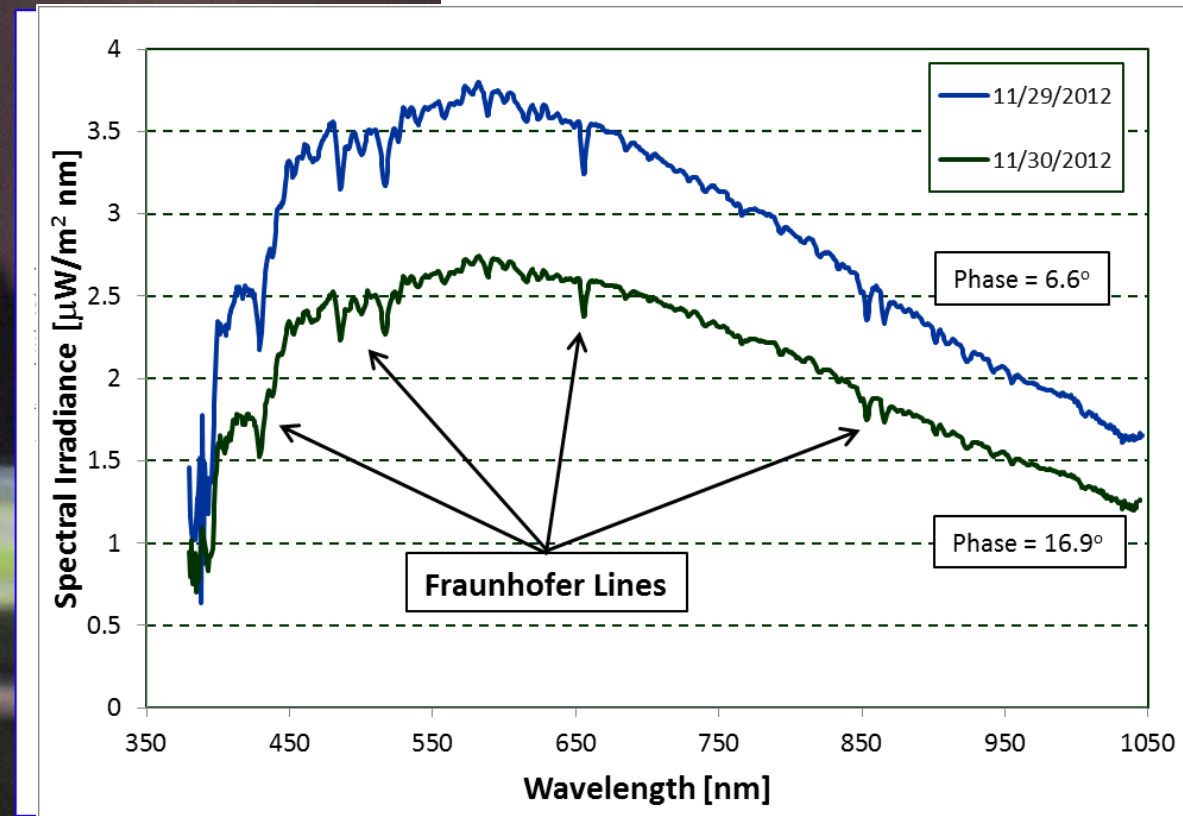
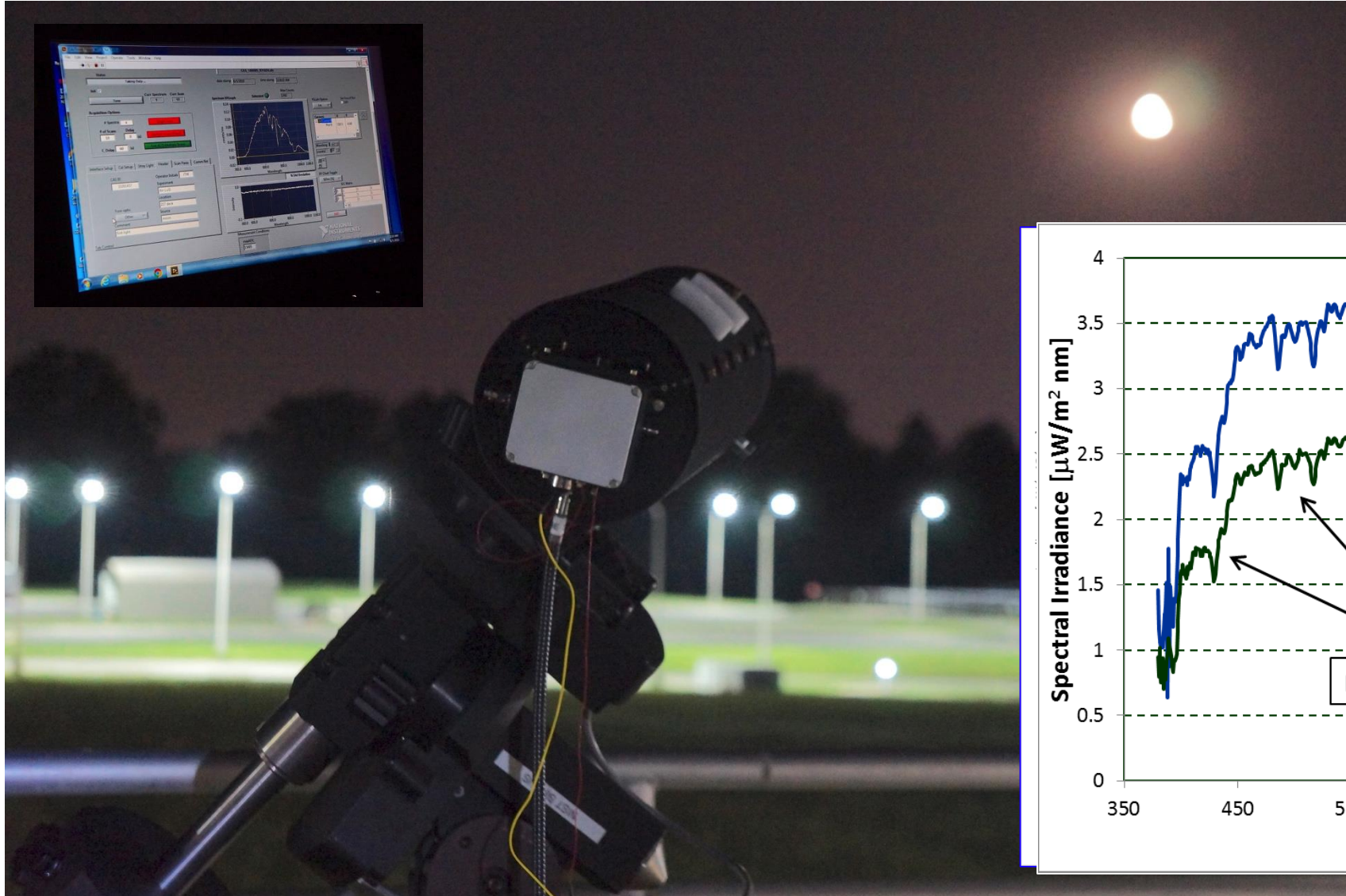
- Single-lens Refractor
- Carbon Fiber Tube
- Invar internal support rings and baffles



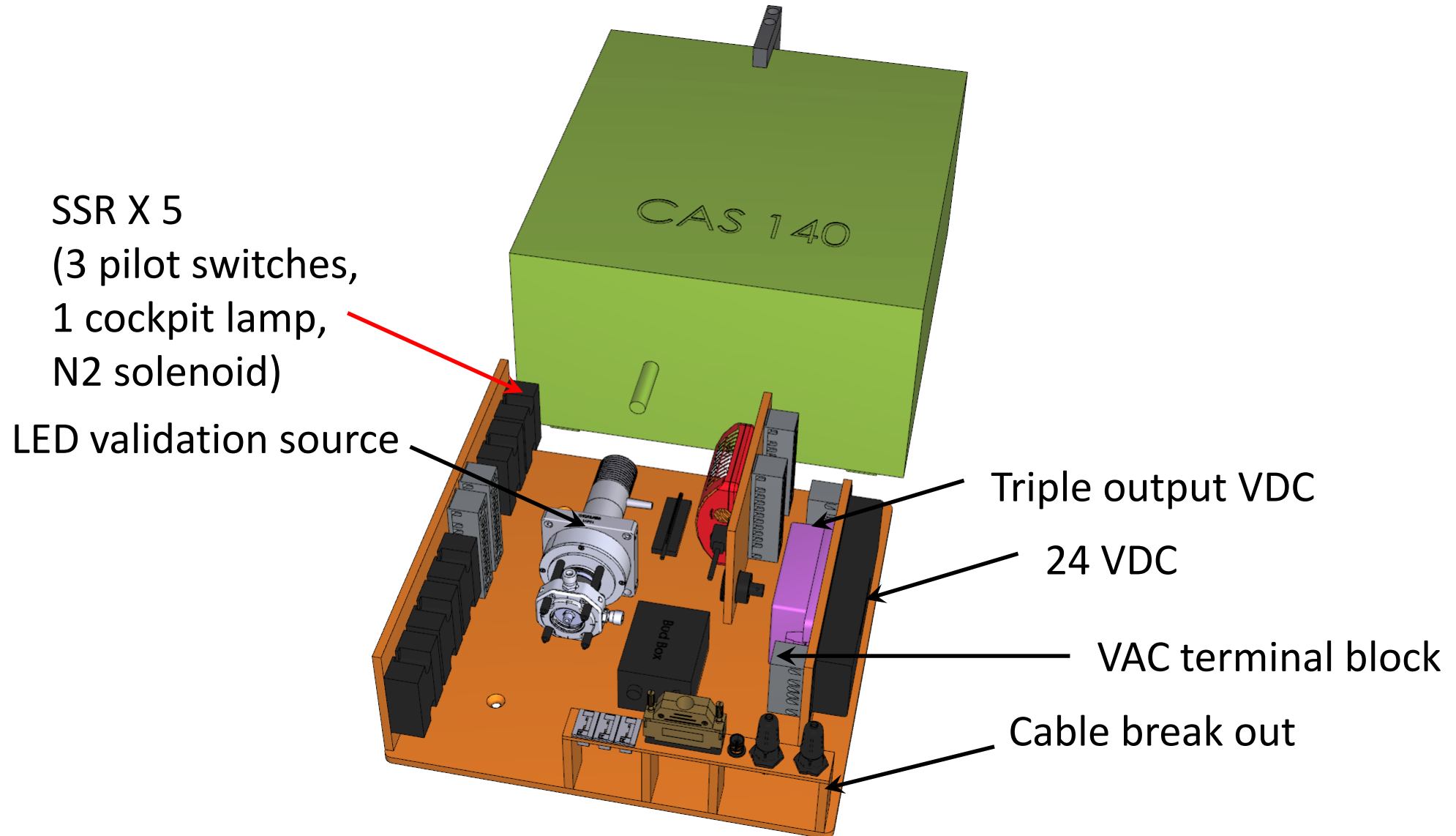
## Integrating Sphere

- Used for collecting light
- Removable
- Improves accuracy
- Scrambles polarization
- Fiber optic ports for
  - Spectrometer
  - LED Validation Source

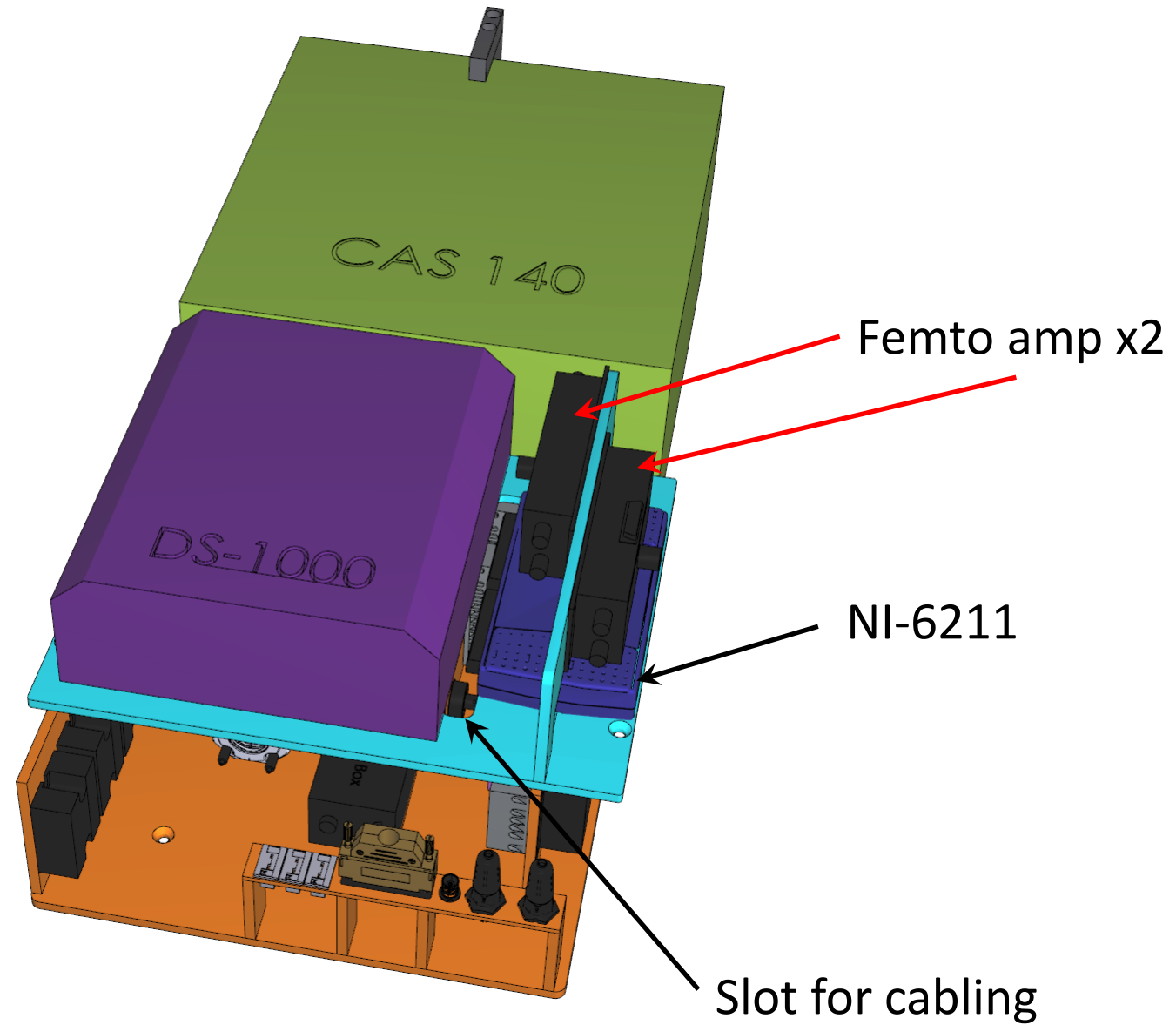
## First Moonlight



## Bottom Level



## Top Level



## Inside Bottom of Enclosure

